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# An investigation of the chemical and metallurgical treatment of a cobalt and nickel ore

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# THESIS

FOR THE

# Degree of Bachelor of Science

IN

# MINE ENGINEERING.

SUBJECT:

"An Investigation of the Chemical and Metallurgical Treatment of a Cobalt and Nickle Ore."

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# Thesis.

## Introductory.

The subject matter of this Thesis may be subdivided under three heads, namely:

Preliminary

Chemical

Metallurgical

treatment of a cobalt nickle ore, the chemical treatment being subdivided into two parts, qualitative and quantitative.

The ore, coming from a district located one hundred and fifteen miles from the nearest railroad point, in a mountainous country, barren of coal, and where freight rates were enormous; demanded a method of treatment not now in general use upon this class of ores, and one that would require as little freight haulage either way, as possible.

With these objects in view, the following work was done, after reading all the data obtainable upon the subject as found in the school library.

## PRELIMINARY.

The ore is principally chlorite, carrying cobaltite, nickolite, pyrite, magnetic iron ore, with here and there scattered nodules of white quartz.

The cobaltite being found principally in the fine seams of the chlorite, and more or less disseminated throughout the same in a very finely divided crystalline state, which on being collected

gave a pinkish cast to the light grey mineral.

As two samples were sent, each was treated separately, but as far as main characteristics were concerned one could not be told from the other in outward appearance, except there was more cobaltite in sample number two than in number one.

The ore was put through a Dodge Crusher down to one-half inch material, then through rolls down to twenty mesh by crushing from one-half inch to one-fourth inch, one fourth inch to one sixteenth inch, and one sixteenth inch to twenty mesh. After each crushing the product was seived on twenty mesh sieve and only oversize recrushed. A small sample through twenty mesh was now removed.

All the twenty mesh material remaining was now sieved on a forty mesh sieve, and the over product crushed in a fine crusher of the Coffee Mill type until all passed the forty mesh sieve. By careful sampling a small sample was removed and ground on bucking board to pass eighty mesh. However, finding the material very hard to make go into solution with acid, the sample was then bucked down to pass one hundred and twenty mesh sieve.

The treatment of sample numbers one and two were carried on at same time and to same extent as far as possible, unless otherwise mentioned.

## CHEMICAL TREATMENT.

The solibility of ore in the commercial acids, separately or collectively, was first tried, hydrochloric acid having only a slight effect, nitric acid being much more active and copious fumes of oxide of nitrogen were given off. Aqua regia ($3HCl$ to $1HNO_3$) gave

still better action and also here dioxide of nitrogen fumes were given off with the free chlorine liberated.

The combination of three acids, Hydrochloric, nitric and sulphuric in ratio of three to one gave best results, sulphuric acid having only slight action after prolonged boiling.

However, no single acid, or combination of acids would act as solvent commercially, as their action was not complete upon the raw ore.

On fusing the ore with sodium carbonate some of the nickle and cobalt present were reduced to metallic state, and formed as pinkish grey beads in the deep blue mass remaining. On treating this fused mass with dilute hydrochloric acid, hydrogen sulphide was given off which precipitated some of the nickle and coblat as fast as it went into solution. The forming of beads could be avoided by first treating sample with acid then making a fusion with remainder that did not go into solution.

A gram sample was then treated with equal parts of powdered charcoal and sodium carbonate, giving same a fusion in assay furnace for thirty minutes.

No larger beads were found than when hydrogen sulphide alone was used. This going to show that carbon would not aid the reduction action taking place during fusing stage to any great extent.

Unless porcelain crucibles are gradually withdrawn from furnace and placed on hot plate the crucible will crack and even then it is hard to prevent unglazing the crucibles. Two fusions generally being enough to unglaze the Royal Berlin Crucible, so no fusion for silica

determination could be made in them,as some of the cobalt would unite with the silica of cru cible at a high heat.

The ore was next assayed to see whether it carried any values in gold and silver. In order to make sure that losses by volatilization in the scorifier method, if any, might be obtained, the ore was also run by the crucible method.

The charge found to work well and recommended by Lodge in the scorifier method was as follows:-

| | | |
|---|---|---|
| Ore | 1/10 | assay ton |
| Test lead | 70 | grams |
| #Silica | 3 | " |
| Borax glass | 5 | " |

Start at low heat and gradually raise heat until action ceases, and charge is ready to pour.

This gave buttons of thirty grams each, which had to be re-scorified, as some nickle and cobalt with arsenic remained.

The crucible charge made up as follows was found to give a good slag and to run well:-

| | | | |
|---|---|---|---|
| Ore | 1/2 | assay | ton |
| Soda | 1½" | " | " |
| Borax | 1 | " | " |
| Silica | ½ | " | " |
| Litharge | 1½ | " | " |
| Salt Cover | ¼" | | |

# Use of silica not recommended by Lodge,but found to be required.

This gave a twenty five gram button which was comparatively free from nickle and cobalt in case of ore number one,but in case of ore number two the buttons had to be scorified with ten grams test lead and three grams borax.

The reason one assay ton of borax is recommended is because it helps make a fusable slag and unites with the oxides of cobalt and nickle.

Salt was found to act as solvent for nickle oxide and cobalt oxide to quite a little extent when in a molten condition.

The buttons thus obtained were cupelled. It was found that if any nickle and cobalt remained in buttons it required a higher heat to oxidize them than is generally required for cupellation,and therefore a serious chance of loosing the silver by volatilization and being carried off by the nickle oxide and cobalt oxide.

By both methods very small beads were obtained and no attempt was made to part them for Silver and Gold.

QUALITATIVE TEST.

Having now gained a general working idea of the behavior of the ore, the qualitative tests were started.

By treating one gram of ore with aqua regia and then fusing insoluble residue with sodiun carbonate all the ore could be made to pass into solution.

The following elements were found, silica, iron, aluminum, arsenic,(trace antimony and bismuth), nickle, cobalt, magnesium and sulphur.

It might be well to note here that if all the arsenic is not

removed you will obtain a test for phosphorous later on. Also that under the above conditions when you come to throw down the second group with sulphur the arsenic being precent as arsenic acid requires prolonged passage of $H_2S$ to reduce same to arsenous acid and then precipitate the arsenic as $As_2S_3$.

It requires three days of twelve hours each to remove all the arsenic in case of ore number two unless the pressure bottle was resorted to. In this case warm the solution to be treated up to a boiling temperature, pass in $H_2S$ gas until solution becomes cold, place in six ounce reagent bottle with ground glass stopper and fill until about twenty cubic centimeters of being full, adding distilled water to make up the deficit. Now charge well with $H_2S$, place stopper in securely, and tie same with string or fine piece of old towel, place in hot water bath and boil for one hour. Remove stopper, pass in $H_2S$ until cool and repeat operation. Two such treatments will generally reduce all the arsenic acid present.

A young man, who checked me on this part of the work, found that if you placed solution to be reduced in some narrow vessel and then passed $H_2S$ and hydrogen into warm solution after manner of oxo-hydrogen tube, all the arsenic acid could be reduced to arsenous acid in three hours.

One peculiarity of the ore to be noticed, especially in the absence of even a trace of copper

QUANTITATIVE ANALYSIS.

After careful reading of material at hand upon this subject, the method as outlined in Furman's Manual of Assaying was

first tried. The fact that arsenic acid was present caused the Iron and aluminum to come down partly as hydroxides and partly as arsenates unless arsenic was removed by sulphur which required too long a time for quick work, made the exact method as given in Hurman too long.

The following methods were considered well worth trying:-

Journal American Chemical Society Vol. 24/1902/ p.578.

"A New Quantitative Test for Cobalt."

One part Cobalt in 500,000 parts water can be detected by following process:-

To five cubic centimeter solution of Cobalt, acid with hydrochloric, add solid ammonium thioacetate ( $CH_3CoSNH_4$ formed) to this a few drops of stanneous chloride solution and an equal volumne of amyl alcohol, or a mixture of acetone and ether, or alcohol and ether. Shake well, allow to separate. If any cobalt is present the upper layer turns blue".

Chemical News. Vol.83/1901/,p 38.

Method there given condensed in following form:

Take the cobalt carbonate dissolve in dilute sulphuric acid and bring the solution nearly to the neutral point by adding ammonia. Then add dihydrogen ammoniun phosphate equal to ten times the cobalt present. At first amorphous violet precipitate is thrown down, changing to deep blue, finally into beautifully crystallized crimson cobalt ammonium phosphate (note that alcohol added makes more complete precipitation). Keep solution hot for ten minutes, wash the precipitate with hot one percent solution ammonium phosphate, then with dilute alcohol. Dry crystals at one hundred and five degrees Centigrade or

less and weigh as double salt ( $CoNH_4PO_4 \cdot H_2O$ ) or ignite and weighas pyrophosphate. ( $Co_2P_2O_7$ )

Potassium nitrate was reommended to be used as agent for separating nickle and cobalt. Owing to the fact that the laboratory did not have in stock dihydrogen ammonium phosphate this method had to be abandoned.

The following method given in Chemical News, Vol. 88/1903/p184 was tried, varying results being obtained. See also Vol. 35/1902/p 270.

" From neutral solution of cobalt and nickle add bromine water and barium carbonate. The cobalt is precipitated as $Co_9O_{14}$ or $Co_7O_{11}$ carbon dioxide and zinc must be absent.

# Dissolve the $Co_7O_{11}$ in hydrochloric acid, add potassium iodide solution and determine the amount of iodide set free (Bunsen Method)

The above method was followed to this extent:

The nickle and cobalt were precipitated as sulphides with $H_2S$ then dissolved in agua regia and evaporated nearly to dryness, any free sulphur filtered off, then evaporated to dryness. Take up with fifty cubic centimeters water one cubic centimeter hydrochloric acid. When clear add barium carbonate until neutral, boil off excess of $Co_2$, cool. Now add barium carbonate in milky form, then fresh bromine water a little at a time, stirring. The solution, now pinkish white begins to turn brown in three minutes, then to black in thirty minutes. An excess of bromine water is necessary. Allow to stand fifteen minutes, to insure complete precipitation of Cobalt. Then filter, the precipitate is $Co_7O_{11}$, $Co_9O_{14}$ and barium carbonate. The nickle is in filtrate also a small portion of Cobalt in every case tried.

# See page

To remove excess of barium carbonate use dilute sulphuric acid. The barium sulphate thus precipitated seemed to carry some of the nickle solution down mechanically and required very thorough gentle washing to remove,also care must be taken not to wash the fine barium sulphate through. . The solution now containing the nickle is determined electrolitically in ammonia solution, two amperes and four and fife tenths volts were used, time four to ten hours,depending upon amount of nickle present.

The following volumetric method for nickle )Bunsen's) was considered a good one,but owing to lack ot time was never tried.

" After separating the nickle from iron take the solution,add a few drops of ammonia until a faint odor, then add five cubic centimeters silver nitrate solution ( five grams silver to 1000 cubic centimeters $H_2O$). Add five centimeters (cubic) potassium iodide solution which gives solution an opalencence color due to pressure of free Ag I. in suspension. Run in a standard solution of Potassium cyanide (1 cc .001 gram nickle) until the solution becomes clear and bright. The titration depends upon fact that so long as there is any nickle uncombined with Potassium cyanide in form of double cyanide the silver iodide will remain undissolved, but as soon as the nickle has all been changed the silver iodide dissolves forming potassium silver cyanide and the solution becomes perfectly clear. Substracting a correction necessary for the titration of the indicator from the total amount of potassium cyanide used, gives the amount necessary for the nickle.

Making up of Standard Solutions used in above Method.

(1) Standard Solution of Nickle.

This can be most easily prepared from pure nickle wire (commercial chemically pure wire being 98.5- 99 percent nickle). Take one gram pure nickle wire calculated from percent wire used, dissolve in beaker with twenty five cubic centimeters nitric acid (1.42) and evaporate just to dryness on water bath. Moisten same with few drops nitric acid and twenty five cubic centimeters water and heat until all goes into solution. Then add fifty to sixty cubic centimeters more of water and to this six grams sodium acetate dissolved in a little water. Heat nearly to boiling until the basic ferric acetates are precipitated. filter, wash thoroughly with hot water. Add to filtrate five cubic centimeters sulphuric acid, transfer to graduated flask and make up to 1000 cubic centimeters (when cool).

Standard Potassium Cyanide Solution.

Dissolve four to five tenths grams of potassium cyanide in water dillute to 1000 cubic centimeters. This must be standardized against the nickle solution. Run in from burette twenty-five to thirty cubic centimeters of nickle solution into an Erlymeyer flask dilute with water to one hundred cubic centimeters add ten cubic centimeters dilute sulphuric acid (2:3) Then add ammonia until slight but faint odor of ammonia is preceptable. Add five cubic centimeters of $AgNO_3$ sol. indicator, and five cubic centimeters - two percent potassium iodide solution, and titrate the mixture with potassium cyanide solution until clear.

To make the correction run, do as above only leave out the nickle solution.

The electrolytic methods given in Furman and elsewhere were tried, but owing to lack of proper facilities had to be given up.

On reading the literature on nickle and cobalt you notice each man claims his method will work, where others he has tried failed to give complete separation.

The following method aimed at rapid work was used in making all tests when accuracy was desired. It however will meet with severe criticism unless followed very carefully, and used upon special class of ore heretofore mentioned.

Five-tenths gram of ore treated with few drops nitric in a number one Royal Porcelain Crucible on hot plate, when action ceases and mass is dry, add two and five-tenths grams $KNO_3$, five-tenths grams potassium chlorate mix well with ore, then add cover of five grams sodium carbonate and around edge sprinkle two and one half grams potassium nitrate . Heat over bunsen burner at low temperature, gradually raising temperature until fusion starts, increasing heat as fusion quiets until you obtain a complete fusion. (blast lamp may be resorted to). Allow crucible to cool but slightly, place on hot plate and when temperature of mads is near boiling add some boiling water and place in casserole. As soon as all the contents have been loosened, break up all large grains with stirring rod, boil with water thirty minutes, filter by decantation, add one hundred cubic centimeters more water and boil fifteen minutes, filter and save filtrates together, repeat with fifty cubic centimeters water four more times, or until all traces of arsenic and sulphuric acid, or sulphates have been dissolved and removed.

The combined filtrates now containing all the arsenic, sulphur and part of aluminum and silica are brought to neutral or slightly acid state by adding $HNO_3$, boil until all $Co_2$ and $NO_2$ are removed, cool solution make neutral with ammonia hydroxide and proceed by the Pierce Method for determining arsenic. The filtrate from arsenic contains the sulphur, raise to boiling point add few drops of hydrochloric to remove excess $AgNO_3$ and filter, to the filtrate add when boiling $BaCl_2$ solution. Allow to stand six hours, and weigh up barium sulphate in usual manner.

The residue not dissolved by water is placed in casserole with burnt filter paper and to this is added sixty cubic centimeters aqua regia and all should pass into solution if fusion was made complete. # Dilute to one hundred cubic centimeters add ammonium hydroxide and ammonium chloride to excess, warm and allow precipitate of iron and aluminum hydroxide to settle, decant on filter, then place all of contents on filter, wash well. This precipitate remove with glass rod from filter paper to beaker, and all that clings with warm dilute HCl (1:10). When all is in solution, warm, add ammonium hydroxide and repeat operation five times or until no trace of nickle or cobalt is held by the precipitated hydroxides of iron and aluminum, this being told by testing filtrate with hydrogen sulphide.

United filtrates (six hundred cubic centimeters or more) and boil down to four hundred cubic centimeters, if any Iron or aluminum hydroxide separte out, remove same by filtration and add to last precipitate of Iron and aluminum. The filtrate should now be a light pink color and slightly alkaline. Add five cubic centimeters ammonia hydroxide and one cubic centimeters acetic acid. When boiling

#If any second group present other that Ag pass in hydrogen sulphide first.

pass in hydrogen sulphide in rapid current for twenty minutes,keeping solution boiling. Then allow solution to boil fifteen minutes more. Towards end just allow to boil. This allows the precipitate to collect in large masses, and go to bottom, then have a filter paper in funnel freshly moistened with boiling hydrogen sulphide water, and filter by decantation at first, at last removing all the contents of beaker onto filter paper. Care should be taken that solution be at boiling temperature and that the filter remains full, otherwise the air and cool solution has a tendency to cause the precipitate to pass into a coloidal solution which is next to impossible to remove when once formed. The filtrate may be tested further with hydrogen sulphide to see that all the third group has been removed, still better,make acid with hydrochloric, then alkaline with ammonia hydroxide and then pass in hydrogen sulphide. However, after prolonged boiling if above conditions were followed you will not find even a trace of nickle and cobalt left.

The sulphides of nickle and cobalt being well washed with boiling hydrogen sulphide water,are now removed to casserole as far as possible by washing off filter paper. All remaining being dissolved by adding a hot solution of Ag. R. diluted to (1:2) and this will leave the filter paper perfectly clean,water being used to remove last traces of dissolved sulphides.

Boil down solution of sulphides until all the free sulphur is lemon yellow, remove by filtering and evaporate the filtrate to dryness, care being exercised not to raise heat above one hundred and twenty degrees centigrade or else the nitrates will decompose,the pink salt turning a dirty brown. When dry add one or two drops hydrochloric acid

and fifty cubic centimeters water, bring to boiling and add KOH solution (rather concentrated) drop by drop, stirring or shaking the solution. The blue and grey clots formed break up and the pink solution gradually looses its color. When supernatent liquor is clear, sign enough KOH has been added and then allow casserole to set on hot plate until the precipitation is complete, this requiring one half hour at least. Filter and the oxides are now dried, ignited and weighed. #The ignited oxides are dissolved with some difficulty in agua regia, boiled to dryness and from here treated by Furman's Method of Separation, using $HgNO_3$ and red oxide of mercury. This however, must be carefully followed or your precipitation will not be complete.

The iron and aluminum from the hydroxides are dtermined in usual way. Also the magnesium from the filtrate of the Nickle and Cobalt sulphides after boiling off hydrogen sulphide and making alkaline with ammonium hydroxide. on separated sample.

The $KnO_2$ and nitroso$\beta$napthol methods were tried for separating nickle and cobalt but as in this case, where cobalt is eight times as much as nickle, was found ~~and weighed~~ to be rather uncertain in results. Also the fact that any nitrates present or any organic matter such as filter paper will prevent the complete precipitation of Cobalt with the nitroso$\beta$napthol method.

By the method given in full the following composition was obtained for ores number one and two:

See Over.

# If much excess KOH used have to boil ignited oxide in ~~$H_2S$~~ $H_2O$ filter, ignite, weigh.

| | No. 1, Percent | No. 2 | Percent. |
|---|---|---|---|
| # | Silica | 48.32 | 36.20 |
| | Arsenic | 4.54 | 18.84 |
| | alumina | 23.28 | 16.65 |
| | Iron | 5.65 | 6.70 |
| | NiO | 0.96 | 3.68 |
| | CoO | 5.00 | 20.54 |
| | Mg. | 2.26 | 1.77 |
| | Sulphur | 2.44 | 10.25 |

In case of ore number two the analysis ran high on account of ore being carried on partly in two samples, and the oxides being tabulated and not the metals.

Ore number one runs low because traces of Bismuth and antimony and water in chlorite were not determined.

From a comparison of the analysis of these two samples we see that the ratio of silica to aluminum trioxide, arsenic to nickle and cobalt combined, magnesium to aluminum trioxide are nearly the same in each case which goes to show that a certain ratio of elements occur, and a quick analysis can be made by obtaining silica , nickle oxide, and cobalt oxide, and figure the remainder by ratio obtained in previous analysis.

## METALLURGICAL TREATMENT.

We now come to the last, but most important part of this thesis, and the one the writer would like to carry on still further as what follows is only the beginning of a vast amount of research work that should be done before a complete report could be made.

# Silica determined by usual method. with precautions included.

Sample number one after being put through forty mesh sieve weighed thirty-five pounds.

This thirty five pounds of material was seived through a set of sieves as follows: sixty, eighty, one hundred, and one hundred and twenty mesh respectively and over size of each carefully saved and weighed separately. This was done to give an idea of the behavior of the ore when crushed to pass forty mesh, and also to determine what degree of fineness of crushing was required to save profitably the concentrates.

The following results were obtained:

| On 60. mesh | On80 mesh | On 100 mesh | On 130 mesh | Thro 120 |
|---|---|---|---|---|
| lbs. | lbs. | lbs. | lbs. | lbs. |
| 8.7 | 2.5 | 3.7 | 0.7 | 19.4 |

Or roughly the following ratio exists, taking on 120 mesh as unity:

| | | | | |
|---|---|---|---|---|
| 13.5 | 3.7 | 5.8 | 1 | 30 |

Samples were taken from each of these sized products after thorough rolling on oil cloth in the above ratio, so as not to disturb their relative proportions.

A sample of forty to sixty mesh material was panned to see if it contained any concentrates and how much. From the fifty gram sample panned not enough concentrates could be found to weigh.

Next sample sixty to eighty mesh was panned but gave no better results than above.

The same was tried on sample eighty to one hundred mesh and a small amount of heads obtained.

This went to show that forty to eighty mesh material could not be concentrated in wet way without further crushing.

To verify this statement, samples of the forty to sixty and sixty to eighty mesh material were spread out on glass slide and placed under compound microscope and magnified from fifty to two hundred times. In this way the structure of these grains could be studied and also the constituents. It could be very clearly seen that the little crystaline particles of cobaltite still clung to the quarts and chlorite grains. So also was the case with eighty to one hundred and one hundred to one hundred and twenty mesh, material, but the amount of cobaltite greatly decreased after sixty mesh material,until at one hundred and twenty mesh only now and then could a grain be found that held any cobaltite.

From this was gained the fact that to obtain good results on a concentration test the original ore must be crushed to pass sixty mesh.

One hundred gram sample from the first sample removed for chemical analysis was taken from ores one and two.

These were panned separately and three products obtained in each case.

Ore No. 1.

| | | | | | |
|---|---|---|---|---|---|
| 100 grams | taken | running | 5.96% Ni. and Co. oxide | | 5.96 |
| 7.7 " | heads | " | 49.34" NiO " CoO | 3.80 | |
| 78.0 " | tails | " | 2.60" " " " | 2.03 | |
| 12.0 " | slimes | " | 2.2" " " " | 0.26 | |
| | | | | | 6.09 |
| | | | | Excess | 0.13 |

Loss 2.3 grams due to solubility of ore and mechanical losses.

Ore No. II.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 100 grams taken running 24.22 % NiO and CoO | | | | | | | gms.24.22 |
| 28.5 grams heads running 50.7% NiO and CoO | | | | | | | 14.45 |
| 49.0 | " | tails | " | 11.60 | " | " | " | 5.68 |
| 21.5 | " | slimes | " | 14.5 | " | " | " | 3.12 |
| 99.0 | | | | | | | 23.25 |
| | | | | | | Loss | .97 |

Loss one gram, due to solubility of ore and mechanical losses. This test goes to show that in case of ore number one sixty four percent of values are saved and are concentrated into eight hundredths of original bulk.

Case of ore number two sixty percent of values are saved and are concentrated to twenty eight hundredths of original bulk.

Also it is well to note that concentrates (or heads) from sample one and two run about the same in nickle and cobalt oxides.

An analysis was made of the heads obtained and gave following results:

| | Ore No. 1 | Ore No. 11 | |
|---|---|---|---|
| S. loss | | 18.07 | 18.07 |
| Fe | 9.12 | 3.56 | 3.56 |
| NiO & CO | 49.36 | 50.72 | 39.90 (Co & Ni) |
| As | 32.86 | 41.10 | 41.10 |
| | | | 102.63 |

A sample one gram each of concentrates from ore one and two were heated in porcelain crucible over bunsen burner and when no more fumes of $SO_2$ or As could be detected the heat was raised to dull

red by using blast lamp. The grey to pinkish grey material blackened, and on weighing the residue obtained, .6450 gm

check .6445 "

or a loss of .3550 gms. due to volatilization of sulphur and arsenic.

This means that by roasting the concentrates they loose 35.5 percent of their weight leaving a product which must run in case of ore number one 75.5% NiO and CoO in case of

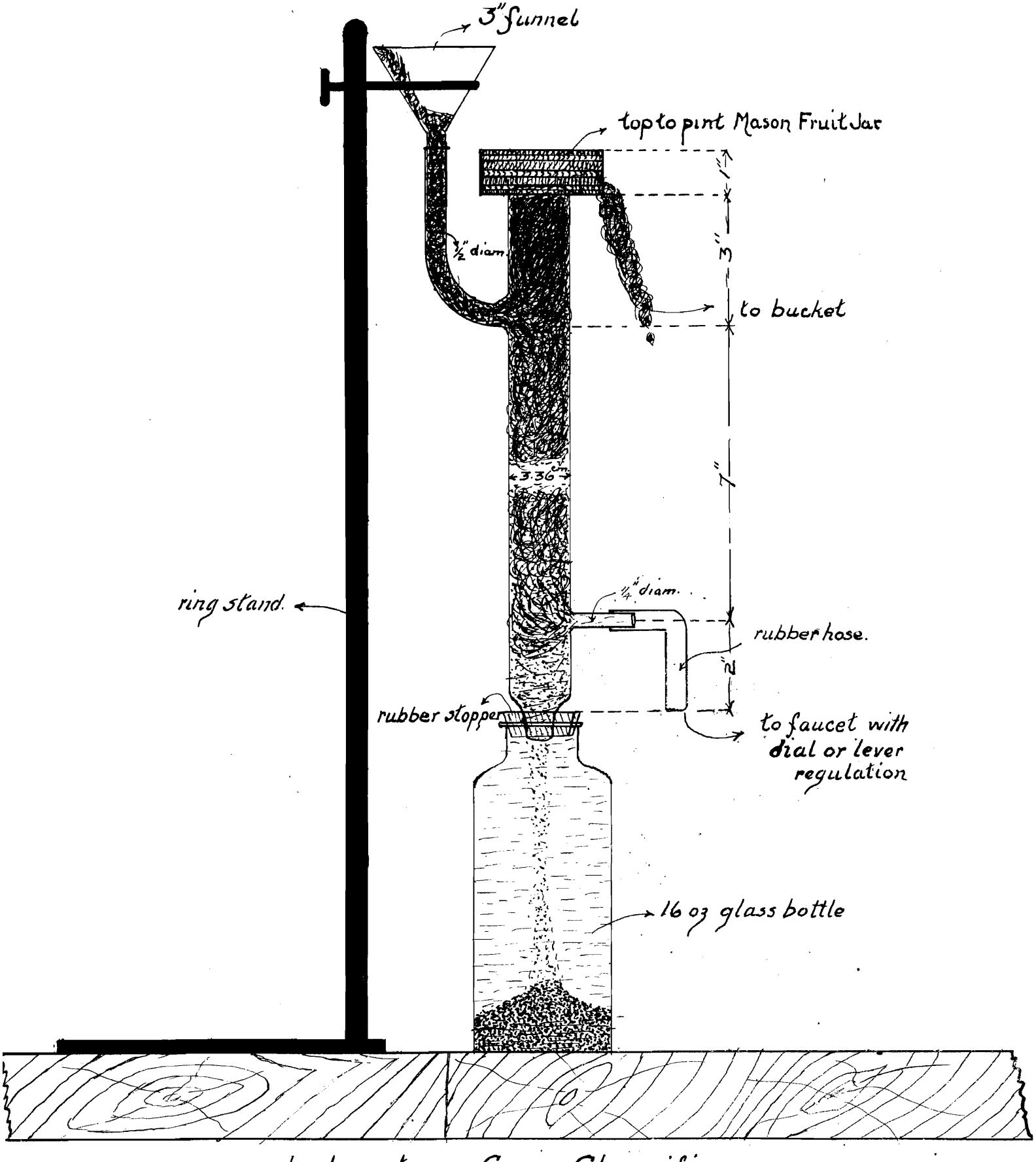
" two 78.6" " " "

This means a product running 60.23% cobalt and nickle in case of ore number one, and 61.9% Cobalt and Nickle in case of ore number two.

Therefore we can safely conclude that material crushed to sixty mesh can be concentrated to sixty perhent nickle and cobalt and save sixty percent of values.

A sample of sixty mesh was next bucked down to pass a one hundred and twenty mesh and this panned, fifty grams giving about three grams heads or six grams per one hundred grams $\frac{6}{7.7} = .78$ and 5.96 X .78 = 4.65 percent which this should run. This was checked by analytical method and found to run 4.88 percent nickle oxide and cobalt oxide. This goes to show that all practical purposes for metallurgical work the concentration pan method will tell close enough the percent of nickle and cobalt the sample runs when same is made to pass one hundred and twenty mesh.

The next step was to classify the material and have it ready to place on table to make a concentration test. To accomplish this end, a laboratory tubular classifier was made by one of the Professors a drawing of same can be seen in Figure One.




Laboratory Cone Classifier

Fig 1

Scale 1" = 3'

A sample of ten pounds made up according to ratio given on page sixteen was used to make the test with. Not know the exact specific gravity of material, I assumed cobaltite to behave similar to cassiterite, and the gangue like quartz. So following ~~the~~ table 250 given on page 466 of Vol11 Richard's Ore Dressing, we would expect a one hundred and twelve mm current to just let the fastest grains, sixty to eighty mesh fall, and a thirty six mm the slowest of the cobaltite present. This means a current giving fifteen pounds of water per minute through classifier for sixty mesh material, ten pounds for eighty mesh, seven and five-tenths pounds for one hundred mesh, and five pounds for one hundred and twenty mesh on fastest settling particle of cobaltite.

To check this a test was first run on five hundred gram sample through eighty mesh (not sized) and results can be seen in Table Two

TABLE TWO.

| | | |
|---|---|---|
| Ore taken 500 gms. through 80 mesh. | gms | 500 |
| 5 pounds water per minute gave | 12 | |
| 3 " " " " " | 52 | |
| 2 " " " " " | 55 | |
| 1 " " " " " | 89 | |
| ½ " " " " " | 79 | |
| Tails (slimes) | 187 | |
| | 474 | 474 |
| Loss | | 26 |

This loss being due to imperfect collecting of slimes, one half hour being allowed for settling between each test, and also due to solubility of ore.

We noice that instead of fifteen pounds per minute five pounds per minute was required before any grains would settle against current. This corresponds to current required for fastest quartz grains of eighty mesh to settle. The twelve grams settling in five pounds water per minute was closely examined but no cobaltite could be found. Same was true of the fifty-two grams in three pounds of water. With this information the ten pounds sample prepared, was run with currents of three, two, one, and one-half pounds respectively and the products saved, also slimes at end.

The product obtained from three pounds current was closely examined and found to have no free crystals of cobaltite present.

The product from two pounds water per minute was placed on Card Table but owing to the small size of same, it being one fourth regular size, no very satisfactory results could be obtained. However, by panning excellent results could be reached.

The writer hates to leave the work in such an incompleted state, but owing to lack of time will have to carry on further tests at some later date, and complete those already started. However, the following conclusions may be drawn from the work accomplished.

The ore can be mined, hand sorted, and crushed by gyratory crusher down to one and one half inch. This one and one half inch material can be sent through set of roughing rolls to one half inch, and then feed wet into stamps having low sixty mesh screens and narrow mortars, using plenty of water, crushing to sixty mesh, and this product sent to a cone classifier where a current corresponding to three pounds be used. The over product going to a three section box classifier

using hydraulic water corresponding to two - one, and one half pound current respectively and the over product sent to sludge pond.

The hutch product from cone classifier can be thrown away. The spigot product from the box classifier can be sent to three sets of Wilfley Slime tables, regulated in speed for each classified prdduct it receives.

The heads obtained should run fifty percent Cobalt and nickle oxides. These being collected can be sent to dryer, then to some mechanical roaster and a eighty percent product of Cobalt and Nickle oxide turned out.

Wood of course or charcoal being used as fuel for roasting. The cost of plant would depend largely upon whether the company desired to increase the capacity cheaply. Atleast $30,000 would be required to construct such a plant to treat one hundred tons of ore in twenty four hours and $50,000 to treat one hundred tons in ten hours.

It might be well to note here that the concentrates contained some magnetic iron ore which could be readily removed by magnetic separator.

# Bibliography.

## A.J.C.

Vol. 31- Page 317 -18

Co., Ni., Chloride, nitrate, and sulphate solutions.

Vol. 28 p 59 Action of fused $Na_2Co_3$on nickle

p/59 Nickle Nicklic oxide.

Vol. 26/1901/p 522, 391, 521,

Action Ni $NH_4$- NiK, $NiSO_4$ on $H_2O_2$

Double Haloids of Niclke and Cobalt.

Vol. 25/1903/ p 95

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Co. and Ni. rapid electrolytic separation method.

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